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Microporosity, the wetted layer and the role of CO and CO_2 driving the activity of comets 29P/Schwassmann-Wachmann and 17P/Holmes

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Abstract

In a previous paper [1], it was shown that melting of cometary ices will occur in the near-surface of some cometary nuclei where the escape of volatiles is restricted by a *microporous* matrix held together by surface tension forces: the so-called 'wetted layer'. In this paper, two distinct melting regimes are discussed, namely; **(a)** an 'hydrophobic' regime at heliocentric distances, r_h of ~4-10 AU, where the melting of hydrocarbons and especially ethane (C_2H_6) ice is likely to dominate, and **(b)** at r_h of ~1.5-4.0 AU, where oxygenated, 'hydrophilic' species are more likely to exist in the liquid phase. Literature data show that the thermophysical properties of carbon monoxide (CO) favour solution of this gas in light hydrocarbons, in particular in liquid methane (CH_4) and liquid propane (C_3H_8) near to their melting point (85-90 K). Consequently, CO must also dissolve in liquid C_2H_6 at very low ambient pressures (<10 Pa). Similarly, carbon dioxide (CO_2) has an affinity to dissolve in methanol (CH_3OH) and CH_3OH-H_2O mixtures at low temperatures and pressures, and especially when approaching freezing point. Thermal gradients within the near-surface generated by the diurnal rotation of the nucleus will concentrate gas solutes in both hydrophobic and hydrophilic environments. Temperature rise and a rapid loss in ambient pressure can result in supersaturation and an explosive release of gas leading to an associated cometary outburst. Thermal cycling can also result in the gradual migration of volatile ices from deep within a *microporous* nucleus. New observations of comets 29P and 17P, including new observational evidence of the anomalously slow rotation rates of their nuclei, support these hypotheses.

1. Outbursts of 29P/Schwassmann-Wachmann and the role of CO

Although Comet 29P occupies a near-circular orbit at r_h of 6.2 AU and so is exposed to relatively uniform degrees of insolation, it is the most active comet known having almost certainly outburst several times each year for the last century, with some outbursts exceeding 5-6 magnitudes in brightness. The most abundant, potentially-active known cometary species able to exist in the liquid phase at the distance of 29P, where subsurface temperatures of 90-110 K are encountered, comprise the compounds;

CO, nitrogen (N_2), CH_4 and C_2H_6

Of these, the most likely species to exist in the liquid phase is C_2H_6 given its triple point pressure of 1.1 Pa. CO gas is very soluble in low-molecular-weight alkanes near their freezing point and also exhibits a high temperature dependence for its Henry constant (especially in liquid CH_4). Such properties favour CO supersaturation as a credible mechanism for the outbursts of 29P given that the nucleus is relatively large and probably a very slow rotator.

Observations using the two 2.0-m Faulkes telescopes of outbursts of Comet 29P in 2010, 2011 and 2012 show discrete patterns in outflowing material which were then followed by repeat outbursts ~60 days later, and which also exhibited outflows having a similar pattern or 'fingerprint'. These findings are consistent with a nucleus rotation period of ~60 days and indicate that discrete sources on the nucleus may be responsible for some repeat outbursts. Unusually, outflows tend to be ejected aligned in specific directions, and are sometimes characterised by paired flows moving in roughly opposite directions.

Wetted layers have considerable cohesive strength enabling significant pressure to build up in cavities where diurnal thermal cycling, and especially increasingly negative temperature gradients induced in the near-surface by nighttime heat losses to space, generates low-melting-point mixtures of liquid CH_4 / C_2H_6 which can absorb large quantities of CO gas: the lower the temperature, the more gas is dissolved. Subsequent daytime heating of the surface then causes a gradual reversal of the temperature gradient vs. depth liberating increasing amounts of CO gas from solution. The cavity pressure may gradually increase as a result, held in place by the strength of the overlying wetted layer, which acts as a semi-rigid mantle or 'plate'. When the pressure is sufficiently large to dislodge the plate, pressure above any liquid in the cavities can suddenly be lost. This causes the liquid to become supersaturated in dissolved CO. Near simultaneous 'ex-solution' of the gas takes place further lifting the plate and the expanding gases propel a jet of material from each of several discrete locations around its perimeter often in almost diametrically opposed directions: hence the unusual observed patterns for 29P outflows reported here.

2. Historic and new outbursts of 17P/Holmes and the role of CO_2

Comet 17P/Holmes is famous for its super-outbursts of 1892 and 2007. Other less energetic outbursts of this comet have also taken place: one in 1893 January and others observed by amateur astronomers in 2008, and by the author and colleague G. Faillace in 2009 January, and in 2012 May. Observations of the 2007 outburst of 17P including new analyses of the developing inner coma indicate a nucleus rotation period of ~44 days.

The wetted-layer mechanism [1] can be invoked to explain the outbursts of this Jupiter-family comet (r_h=2.1-5.2 AU) where slow diurnal cycling in an hydrophilic environment can produce aqueous mixtures in the liquid phase. In particular, CH_3OH-H_2O mixtures can dissolve large amounts of CO_2, which can readily supersaturate and drive outbursts. Literature thermophysical data for saturated liquids at 1 atm pressure (10^5 Pa) show that the solubility of CO_2 attains a massive 0.25 mole fraction in liquid CH_3OH at 195 K, and that this is almost identical to the solubility of CO in liquid CH_4 at 92 K at the same pressure. CH_3OH-H_2O mixtures are liquid at very low temperatures, and form a monohydrate melting at 157 K. There is therefore plenty of scope for CO_2 supersaturation conditions to be reached and to drive outbursts of 17P provided that *microporous* regions of the nucleus form wetted layers trapping subsurface cavities where liquids can accumulate. If other hydrophilic species such as formaldehyde (HCHO) and hydrogen sulphide (H_2S) are present then these too may also lower melting points enhancing CO_2 solubility. Thermal conditions at the nucleus may also permit both hydrophilic and hydrophobic environments to coexist in different regions of the surface at the same time.

2.1 A replenishment mechanism for volatiles in the near-surface of comets

Gas-driven outburst mechanisms based on the amorphous-to-crystalline phase transition of H_2O ice fail to properly account for outbursts of Comet 17P occurring several years after its perihelion passage during the 'cold phase' of its orbit. *Microporosity* is an essential property of cometary nuclei permitting some chemical species to exist not only in liquid form but also as the basis of a second novel mechanism outlined here by which diurnal thermal cycling enables the gas-phase migration of frozen volatiles towards the surface from a significant depth within the nucleus. The mechanism is explained in terms of gas-solid adsorption isotherms in which the adsorption-desorption process exhibits hysteresis due to preferential capillary filling of the smaller micropores present in the subsurface. This novel transport mechanism may for instance account for;

(a) the late outburst, reported here, of 17P/Holmes in 2012 May at r_h = 4.4 AU returning from aphelion,

(b) the 1991 outburst of 1P/Halley at r_h = 14 AU.

(c) the existence of detectable H_2O ice at the surface of an outer Main-Belt asteroid such as (24) Themis.

3. Summary

In this paper, a new paradigm is introduced to better describe the complex physicochemical processes that occur beneath the surfaces of some cometary nuclei. Although comets contain a wide variety of compounds, the low temperatures largely preclude chemical reactions *per se*, favouring instead several physical processes involving solid/liquid/gas phase changes in a *microporous* matrix subject to thermal cycling to transport volatiles and drive some types of cometary activity.

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References

[1] Miles, R., Faillace, G., 2012. On liquid phases in cometary nuclei. Icarus 219, 567-595.